Livestock Manure Impacts on Groundwater Quality in Alberta

2008 to 2011 Progress Report

Alberta Government

Livestock Manure Impacts on Groundwater Quality in Alberta

2008 to 2011 Progress Report

Kristen Lorenz[1], Mike Iwanyshyn[2], Barry Olson[3], Andrea Kalischuk[3], and Jason Pentland[1]

[1] Alberta Agriculture and Rural Development, Edmonton
[2] Natural Resources Conservation Board, Calgary
[3] Alberta Agriculture and Rural Development, Lethbridge

Alberta Agriculture and Rural Development

2014

Citation
Lorenz, K., Iwanyshyn, M., Olson, B., Kalischuk, A., and Pentland, J. 2014. Livestock Manure Impacts on Groundwater Quality in Alberta: 2008 to 2011 Progress Report. Alberta Agriculture and Rural Development, Lethbridge, Alberta, Canada. 316 pp.

Published by
Irrigation and Farm Water Division
Alberta Agriculture and Rural Development
Lethbridge, Alberta, Canada

Printed in Canada

Copies of this report are available from
Water Quality Branch
Alberta Agriculture and Rural Development
Agriculture Centre
100, 5401 – 1 Avenue South,
Lethbridge, Alberta, Canada, T1J 4V6
Phone: 403-381-5140

Mapping and graphics:
Bonnie Hofer
Andrew Sommerville

This is a progress report of an ongoing research study. Results and interpretation presented in this progress report are preliminary.

Executive Summary

1 Introduction

The agricultural industry is under increasing pressure to publically demonstrate effective environmental stewardship practises for agricultural production including livestock production and associated manure management. Confined feeding operations (CFOs), such as feedlots and dairies, often manage manure by storing it and then applying it on adjacent cropland. While manure is an important source of nitrogen (N) and phosphorus (P) for crop production, the nutrients and pathogens in manure have the potential to reduce the quality of groundwater, which is an important source of water in many parts of the province. In particular, manure application and the potential seepage of liquid manure storage from earthen manure storages (EMSs) have been previously identified as potential concerns for groundwater quality.

Much of Alberta's agricultural areas are located on hydrogeologically stable sites as a result of the prevalence of relatively thick clay and till (fine-grained soils) throughout much of the landscape. The thick clay and till can limit transport of surface contaminants into groundwater. Groundwater in Alberta also tends to be relatively deep, and shallow aquifers that might be at risk to contamination from surface activities are not extensive. However, deep fractures are common in clay-rich sediments in Alberta, and these fractures may increase the migration of contaminants to greater depths and into underlying aquifers. Furthermore, agricultural areas over unconfined sand aquifers (i.e., exposed to the ground surface) or bedrock overlain by a thin layer of surficial sediments may also be vulnerable to contaminant movement from the ground surface. Recent literature reviews concluded there are limited data available regarding the impacts of manure storage and spreading on groundwater quality in Alberta and that additional research is required.

Alberta Agriculture and Rural Development initiated a 6-yr field project to examine and better understand the impact of EMSs, CFOs, and manure spreading on groundwater under characteristic Alberta hydrogeological conditions. This project was initiated in November 2008 and is anticipated to be completed in December 2015. This report summarizes the progress of the project from 2008 to 2011.

2 Objectives

The overall objective of this project was to improve the understanding of the fate and transport of manure constituents in groundwater in Alberta. Specific objectives included:

1) Determine groundwater quality changes with time in the Battersea area; which has extensive irrigation, a high density of CFOs, and historical groundwater data.

2) Determine risks to groundwater quality from manure field application and storage facilities.

3) Compare relative impacts between manure field application and storage facilities on groundwater quality.

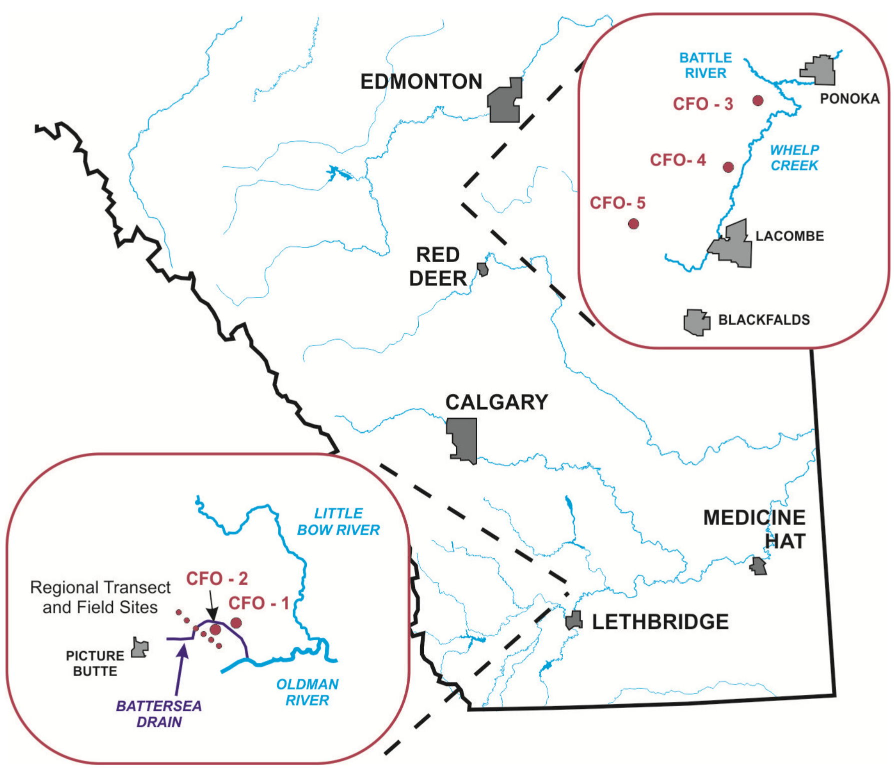
3 Scope

The project involves the study of groundwater impacts associated with:

1) Manure spreading
    - Battersea Regional Transect Study
    - Field-scale Manure Spreading Study
2) Earthen manure storages and CFOs

The two project components were investigated in two study areas that were selected to represent different geologic and hydrogeologic conditions in the province. The regional transect study was conducted in the Battersea area, east of Picture Butte. The effects of EMSs and CFOs on groundwater quality were investigated in the Battersea area of southern Alberta and the Lacombe-Ponoka area of central Alberta, while the effects of manure spreading on groundwater quality were only investigated in the Battersea area.

The study generally focused on the shallow groundwater environment where impacts from activities on the land surface are likely greatest. Understanding the vertical movement of contaminants to deeper groundwater environments is also required to assess contaminant transport and natural attenuation mechanisms. Nitrate N (NO_3^--N), ammonia N (NH_3-N), and chloride (Cl^-) were used as the main contaminant indicators in this project.



Location of main study areas.

4 Design, Progress, and Key Points

4.1 Battersea Regional Transect Study

Groundwater quality from a regional transect of wells in the Battersea area was compared to historical water quality data from about 10 yr ago to determine changes with time. Current groundwater elevations and shallow groundwater flow direction were similar to historical data. Increases in NO_3^--N and/or Cl^- were observed in all nine wells when compared to the historical data, suggesting that NO_3^--N and Cl^- continues to enter the shallow groundwater environment.

A previously established regional transect of 23 wells in the Battersea area, east of Picture Butte, Alberta, were re-activated and monitored from 2008 to 2011. Results from nine of these wells were compared to previous work carried out about 10 yr ago (1994 to 2001) to determine changes in groundwater quality with time.

Field work from 2008 to 2011 included the installation of new water table wells and piezometers, re-establishment of historical wells, water table elevation monitoring, groundwater sampling, surveying of wells, and the collection of soil samples for chemical and isotopic analyses. Transect site locations and methods were chosen in an attempt to be consistent with the historical work in order to compare groundwater quality between the two sampling periods and provide a representative cross section of geologic, hydrogeologic, and anthropogenic conditions within the Battersea area.

Groundwater elevations measured in the current study were consistent with groundwater elevations previously measured, and the results indicated a general flow direction from northwest to southeast in the area, i.e., from the bedrock high to two rivers along the east and southeast study area boundary. Water table elevations increased in the spring and early summer in response to spring runoff, summer rainfall, and irrigation of the fields, and then declined through the fall and into the winter.

Nitrate-N and Cl^- average concentrations were significantly elevated in four of nine wells from 2009 to 2011 compared to historical measurements (1994 to 2001). In the other five wells, either NO_3^--N or Cl^- average concentration was significantly increased from the historical to current monitoring periods; whereas, the other parameter concentration either did not change (three wells) or significantly decreased with time (two wells). These increases suggest that shallow groundwater within the Battersea study area continues to be influenced by activities on the land surface.

4.2 Field-scale Manure Spreading Study

Four field sites with a history of beef manure application were instrumented in the Battersea study area to determine the risk of manure spreading on groundwater quality. Field sites represented typical geological conditions of the area. Nitrate N and Cl^- concentrations varied among field sites and shallow and deep wells. The highest concentrations were measured in groundwater from the shallow wells at the field sites with coarse-grained soils. Subsequent

years of study will continue to assess impacts on groundwater quality from individual field sites.

The field-scale study has two main components: groundwater monitoring and nutrient budget assessment. Fields were selected to represent typical geological conditions in the Battersea area, including a fine-grained soil (Field A), a coarse-grained soil (Fields C and D), and a transitional soil between the fine-grained and coarse-grained soils (Field B). All four fields have a history of beef manure application and the soils contain an excess of soil-test phosphorus (98 to 699 mg kg^{-1}).

A total of 50 wells were instrumented among the four fields. Existing and new water table wells and piezometers on the periphery of the fields were used to determine groundwater flow direction, horizontal and vertical hydraulic gradients, and the upgradient and downgradient concentrations of nutrients in groundwater. Manure and soil samples were also collected.

Groundwater elevation in the shallow and deep wells was influenced by the geologic conditions at each site and, in some cases, by precipitation and irrigation events. A dynamic response to precipitation, irrigation, and purging and sampling events was observed in the shallow wells in the fine-grained soil (Field A) with less of a response in deeper wells. At the transition site (Field B), groundwater elevation was responsive to purging and sampling events at all wells (shallow and deep) in the lacustrine deposits, which acted as a single hydrological unit. Water levels in shallow and deeper wells were generally influenced by precipitation events in coarse-grained soils (Fields C and D). Recharging conditions (downward gradient) were generally found at all four field sites.

Nitrate N and Cl^- concentrations varied among field sites and shallow and deep wells. The highest NO_3^--N and Cl^- concentrations of all four fields were measured at Fields C and D, the sites with coarse-grained soil. Concentrations were generally low at depths greater than 8 metres below ground surface (mbgs). However, there was some downward migration of Cl^- in a few deeper wells, suggesting possible localized transport of manure constituents to depth at Fields C and D. Nitrate N and Cl^- were elevated in the shallow water table wells at Field B, the transition site, but were not present at depth, suggesting transport of manure constituents to depth did not occur at Field B. Of the four field sites, Cl^- and NO_3^--N concentrations were generally lowest in the water table wells at Field A, the site with fine-grained soil. A seasonal pattern was observed for Cl^- and NO_3^--N with higher concentrations in spring (May and June) at this site. In one corner of Field A, groundwater and soil Cl^- and NO_3^--N concentrations increased with depth to 10 mbgs before decreasing again. The cause of the elevated concentrations with depth is not known.

4.3 Earthen Manure Storage and Confined Feeding Operation Study

Five CFOs were instrumented to determine the risks to groundwater quality from manure collection and storage facilities. Nitrogen and Cl^- concentrations were generally elevated near the EMSs and catch basins at the five CFOs. Subsequent years of study will continue to assess plume migration from the EMSs and the overall impact from the CFOs on groundwater quality.

Five CFO sites were selected: two in southern Alberta, near Picture Butte in the Battersea area (CFO-1 and -2), and three in central Alberta, in the Lacombe-Ponoka region (CFO-3, -4 and -5). The CFO-1 site includes a dairy with an EMS and a feedlot with pens and a catch basin. The CFO-2 site is a feedlot with pens and catch basins. The three CFOs in central Alberta are dairies each with an EMS. The sites represent four geological/hydrogeological conditions: sandy/permeable (CFO-1), thick till and clay (CFO-2), thin till overlying permeable bedrock (CFO-3 and -4), and thick, permeable unconsolidated deposits overlying bedrock (CFO-5). There are a total of 72 groundwater monitoring wells among the five CFO sites.

Data collected from 2009 to 2011 included groundwater elevations, groundwater chemistry and isotopes, manure chemistry, soil chemistry, and vertical and horizontal hydraulic gradients. Geophysical investigations were conducted at some of the sites to obtain qualitative information about the extent of any groundwater quality impacts.

Nitrate N, Cl^-, and NH_3-N concentrations varied among well nests and well completion depths at CFO-1. The highest concentrations were measured in wells immediately surrounding the EMS (about 1 m from the EMS). Liquid manure storage lagoons (earthen manure storage) constructed using natural materials are expected to have certain amount of seepage. Subsurface natural attenuation processes (e.g., sorption) are relied upon to minimize risk of any seepage on groundwater quality. Elevated NO_3^--N and NH_3-N concentrations in a deeper piezometer (8 mbgs) near the EMS may indicate downward movement of contaminants. Similar results were observed for the catch basin. Preliminary geophysical investigation at CFO-1 showed a plume of high electrical conductivity next to the EMS and approximately 10 to 15 m downgradient from the EMS. Relatively low electrical conductivity values were observed less than 50 m downgradient from the EMS.

Ammonia N concentration at CFO-2 was highest in the downgradient wells, while Cl^- and NO_3^--N concentrations were elevated throughout the entire site. Concentrations greater than 10 mg L^{-1} in nearly all water table wells at CFO-2 indicate agricultural activities are influencing shallow groundwater; however, the elevated concentrations in the upgradent wells indicate the source may be from manure spreading areas upgradient from the CFO in addition to the CFO. There does not appear to be downward movement of manure constituents from this CFO.

Nitrate N and Cl^- concentrations at CFO-3 were elevated in groundwater from the wells immediately surrounding the EMS. Concentrations were low in deeper wells (16 and 21 mbgs). Electrical conductivity readings from the geophysical investigation were not noticeably greater in the assumed downgradient direction of groundwater flow from the EMS as compared to upgradient readings, and a plume from the EMS was not identified.

Nitrate N and Cl^- concentrations at CFO-4 were elevated in the water table wells immediately surrounding the EMS relative to the background and deeper wells. Groundwater chemistry in wells adjacent to the EMS (about 2 m from the EMS) combined with the geophysical investigation suggested that shallow groundwater (from 2.9 to 7.5 mbgs) has been impacted near the EMS. The geophysical investigation also showed elevated electrical conductivity values north of the EMS, and these higher values may be due to impacts to the shallow groundwater originating from the EMS.

Nitrate N and Cl^- concentrations at CFO-5 were generally higher in the shallow water table wells surrounding the EMS than in the upgradient wells or deeper piezometers surrounding the EMS. Similar to the other CFO sites, the elevated concentrations in the shallow wells around the EMS indicate leaching from stored liquid manure, which has impacted the shallow groundwater. Elevated NH_3-N at depth (14 and 21 mbgs) also indicated manure constituents have moved to depth at this site.

4.4 Comparison of the Relative Effects of Manure Spreading and Confined Feeding Operations on Groundwater Quality

The relative impacts of manure spreading and CFOs on groundwater quality will continue to be assessed. Subsequent years of study will involve work to better understand the impact from individual manure sources and beneficial processes such as natural attenuation, including denitrificaiton, and groundwater mixing.

Data collected from the four field sites and the five CFO sites in the Battersea and Lacombe-Ponoka areas will be used in combination with source assignment and source contribution assessments to compare the relative impacts of manure spreading and manure storage on groundwater quality.

An understanding of the impact from individual manure sources (manure spreading, EMSs, and CFOs) is required before comparisons can be made. Tracers that are mobile in groundwater and unique to the EMS, CFO, and manured field sites are required to distinguish among the three sources as well as from other anthropogenic sources. Biological indicators, isotope signatures, and dissolved gas ratios will be investigated to assess if they may be used as unique tracers to differentiate the sources prior to and after biogeochemical processes and mixing of groundwater that may alter the chemical makeup of the plume.

Comparisons of Cl^-, NO_3^--N, and NH_3-N concentrations will allow for preliminary assessments of individual source contributions to groundwater, while taking into consideration site specific differences in geology, hydrogeology, and natural attenuation, such as denitrification. It is expected that NH_3 will be the form of nitrogen observed in close proximity to the EMSs, while NO_3^- will be the form of nitrogen measured beneath manured fields.

Mass flux and discharge will be estimated using isocontours and solute transport modelling in subsequent years. These estimates will be used to compare the relative impacts of manure spreading and storage activities under different geologic and hydrogeologic settings.

5 Future Work

Routine monitoring and sampling of groundwater (elevation and quality), soil, manure, and collection of land use and management data will continue at all study sites. Additional isotope analyses in subsequent years will be used to assist in data interpretation. Geochemical and hydrological conditions of the study sites will be better understood through additional work such as point velocity probe sampling and hydraulic conductivity testing.

Twelve additional historical wells were re-activated in 2012 to expand the wells used in historical comparisons. A more detailed statistical analysis of groundwater chemistry will be carried out to assess trends in groundwater quality in the Battersea area.

At the field sites, a nutrient budget will be used to estimate the loading to groundwater of potentially leachable total N and Cl^-. The nutrient budget will provide insight into the impacts to groundwater from manure application to the fields. If possible, a control field to which no manure has been applied will be instrumented within the stratigraphic regions of the study to provide a background comparison.

At the CFOs, a water balance will be conducted for each EMS, and additional wells will be instrumented at the CFOs in central Alberta to help assess the impacts of the facility. Geophysical measurements will be used to supplement current monitoring and data using less intrusive measures. Work will continue toward delineating the plume, vertically and horizontally, from each EMS.

Acknowledgements

The following individuals contributed a tremendous amount of expertise and effort toward this project: Ki Au, Wiebe Buruma, Janna Casson, Taren Cleland, Dana Coles, Sarah Depoe, Paul Graveland, Andrzej Jedrych, Mark Kadjik, Adelle Kientz, Doug Knowles, Brian Koberstein, Joanne Little, Gyan Mankee, Cory McIsaac, Brock McLeod, Lynda Miedema, Vince Murray, Colleen Phelan, Murray Peters, Mike Sajjad, and Janelle Villeneuve of Alberta Agriculture and Rural Development; Walter Ceroici, Jim Fujikawa, Barb Hazelton, Tim Jesperson, and Allasdair McKinnon from the Natural Resources Conservation Board; Virginia Chostner, Jim Hendry, Erin Schmeling, and Jonathan Turchenek from the University of Saskatchewan; and Ron McMullin from the Alberta Irrigation Projects Association. A special thanks to Walter Ceroici and Lisa Tymensen who took the time to review this report.

This project would not be possible without the cooperation of the producers in the two study areas. We also acknowledge the collaboration with and support from the Natural Resources Conservation Board and University of Saskatchewan (U of S) and the funding support from the Alberta Irrigation Projects Association. Additional contributions have been provided by Alberta Environment and Sustainable Resource Development, Universities of Alberta and Kansas, Agriculture and Agri-Food Canada, Natural Sciences and Engineering Research Council (U of S), and Canadian Water Network (U of S).

Table of Contents

List of Figures

List of Tables